TOPOLOGICAL OPTIMIZATION AND GENERATIVE DESIGN OF COMPONENTS THAT ARE PART OF ELECTRIC MOTORS

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ABSTRACT: This paper aims to use topological optimization and generative design to identify the ideal shape and dimensions for the rotor and stator of an electric motor, reducing the production cost and dimensions. After the generative design is made, the parts will be 3d Printed using FDM method.

KEY WORDS: electric motor, generative design, rotor, stator, topological optimization, 3d printing

1. Introduction

In the case of brush motors, the stationary field [stator] is generally created by permanent magnets that interact with a rotating field [rotor] that contains the motor windings. Brushless motors are the exact opposite, because the stator field is the coiled element and the rotating field is the permanent magnet. In both cases, the interaction of these fields produces a torque that rotates the rotor. As the rotor rotates, the winding current is changed or switched to produce a continuous torque. The brush motor usually uses graphite brushes that move on metal bars [the switch] that are connected to the rotor coils. As the rotor rotates, the brushes transfer current from one set of coils to another. Brushless motors are based on their switching by using a shaft position sensor that sends a signal to an external winding switching circuit (Fig. 1). [1]

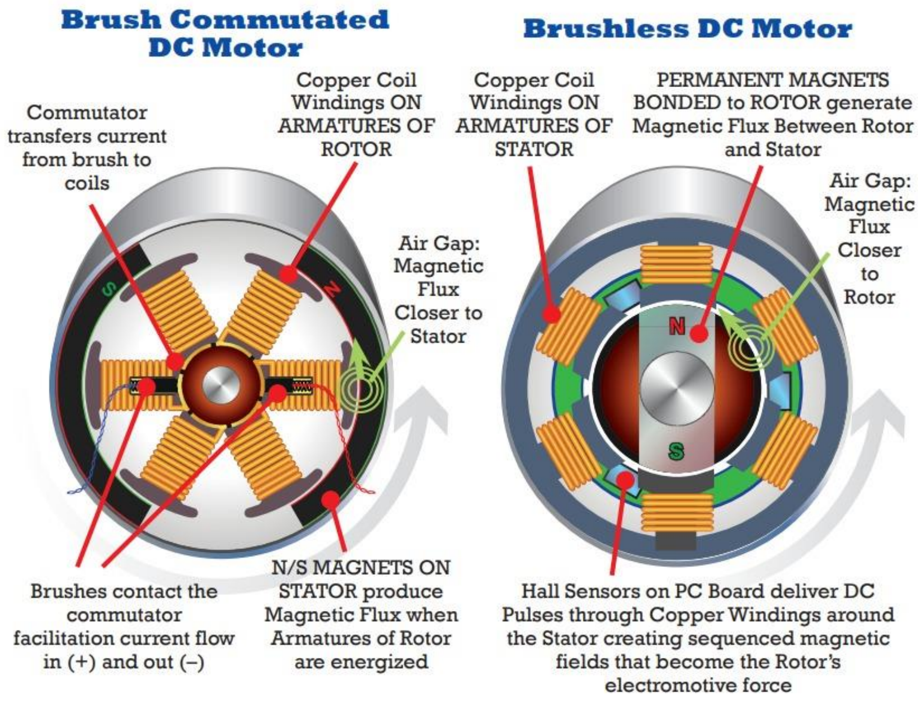

Fig. 1 Schematic diagrams of brushed and brushless motors [1]

Table 1 shows the characteristics of brushed and brushless motors. Due to the better features of the brushless motors, they were chosen to be topologically optimized.

Table 1 Motor characteristics

Characteristics	Brush motor	Brushless motor
Simplicity	They are simpler, as the motor can be powered directly from a power source.	They are more complex requiring an electronic controller.
Torque	-	Generally higher
Speed	1000-10000 rpm	Over 10,000 rpm only with certain configurations
Noise	They are generally noisier	-
Lifetime	2000-5000 hours - limited by the life of the brushes	Over 10,000 hours - bearing life limit
Cost	Generally lower but very dependent on the type of engine	-

2. Current stage

Brushless motors are often used in industrial applications (linear motors, servomotors, actuators for industrial robots, drive motors for extruders, advance drives for CNC machine tools), but also for different types of drones (flying, underwater, etc.).

The aim of this work is to optimize a brushless electric motor that is part of an overflight drone.

For medium and small drones it is effective to use brushless motors due to the fact that they are more powerful and have a long life.

Brushless motors are versatile and easy to customize due to the fact that they can be obtained by other manufacturing methods such as additive manufacturing.

Starting from the need to make electric motors as fast as possible and with minimal initial investment, the team chose to make a brushless electric motor through an additive manufacturing method that will help its construction in a shorter time, while maintaining the characteristics imposed.

The advantage of printing a 3D motor for drones is that the design of the parts can be easily modified and reprinted, depending on the need and the desired adjustments. An engine can be built in about 20 hours. Compared to other drone engine manufacturing solutions, the 3D printing method is low cost and it is important to be able to replace it as soon as possible if the aircraft is destroyed. [2]

A good example of the need for 3D printing of engines for fly drones refers to the current situation in Ukraine, where the activity must be continuously monitored with precision and access to as much information as possible, and if a drone is detected and destroyed, time and the cost of replacing the equipment will be minimal compared to other technological processes for building a new engine and eventually the whole product.

3. Topology optimization with finite element method

Starting from the idea of the current stage where we can use such types of engines in the assemblies used for the manufacture of fly drones, where we depend on the need for a long flight time, high maneuverability and small size, we decided to follow the manufacturing direction by printing 3D (FMD - Fused Deposition Modeling) of the main components that help us meet the needs mentioned above.

Given that the aim is to maintain important criteria for optimal operation, we will use the topological optimization technique with the finite element method that will generate new concepts on the imposed conditions. This technique starts from a preliminary geometry of the parts on which the conditions imposed by the functionality will be applied. The next step is to discretize the benchmark into finite elements that will help achieve a more efficient end result. The resulting parts are then analyzed by a design engineer and used to create new geometries. This topological optimization helps us to reduce the mass of the parts, keeping the imposed functionality conditions.

An electric motor on the market was chosen to have a starting point. It consists of rotor, stator, shaft, bearings, threaded rod, magnets and copper wire.

From the list of the main components that make up the brushless electric motor, the team focused on the rotor and stator parts (fig.2) to be made by 3D printing technology. The modeling of the parts was done in the Autodesk Inventor software starting from a given form and taken from open sources.

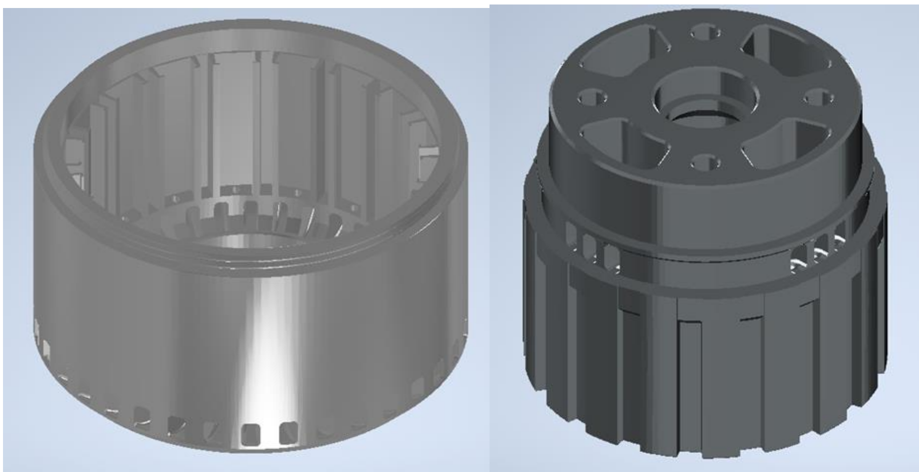

Fig. 2 –Initial model of a) Rotor and b) Stator [3]

Rotor geometry consists of slots used for the insertion of permanent magnets and vents. The rotor must be fixed to the shaft, and it must meet rigid conditions capable of withstanding the centrifugal forces required for operation. By importing the rotor geometry in a generative design software and after formulating the input parameters, 2 objects were obtained, presented in fig.3, which respect the material reduction conditions, streamlining the parameters of the final product.

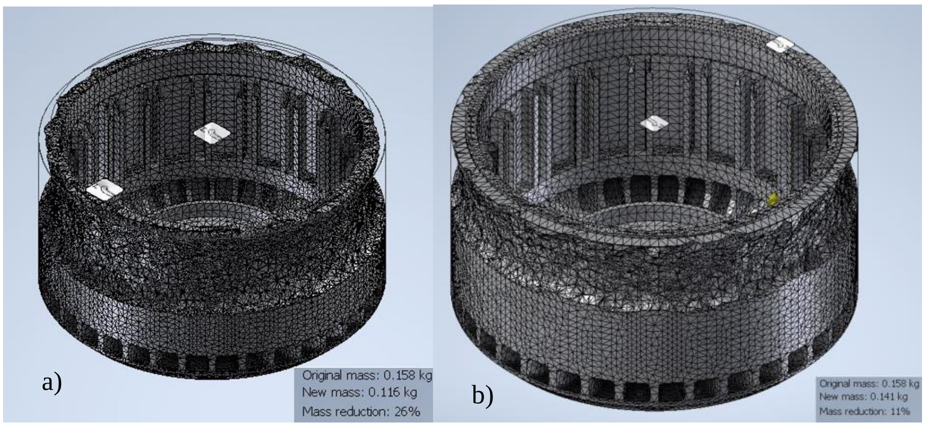

Fig 3 – Parts generated by weight reduction by a) 26% and b) 11%

Following the concepts generated, it can be seen that reducing the rotor mass is possible without this aspect affecting the efficiency of the electric motor, so the team chose to change the appearance of the rotor by introducing at least 1.5 mm channels present on its outside, which have the role of reducing the weight of the rotor.

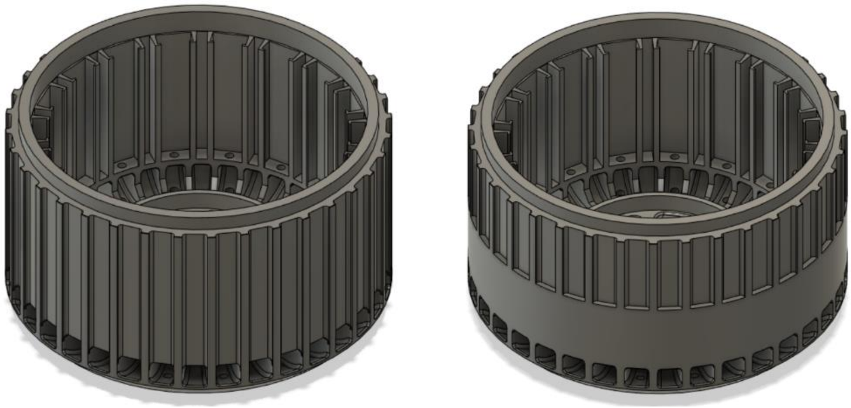

Fig. 4 – Team-generated concepts

The stator is the basis for winding the copper wire. By introducing it in the generative design software, a landmark with a mass reduced by 10% was obtained, presented in fig. 5

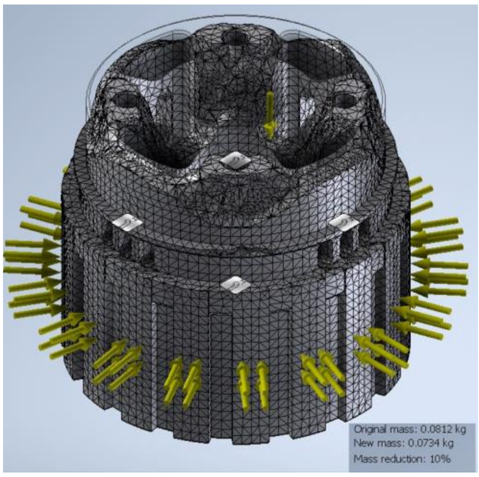

Fig. 5 Part generated for stator

The team also rethought the stator and how we could reduce its weight without affecting its efficiency. Therefore, the following two constructive solutions presented in fig. 6.

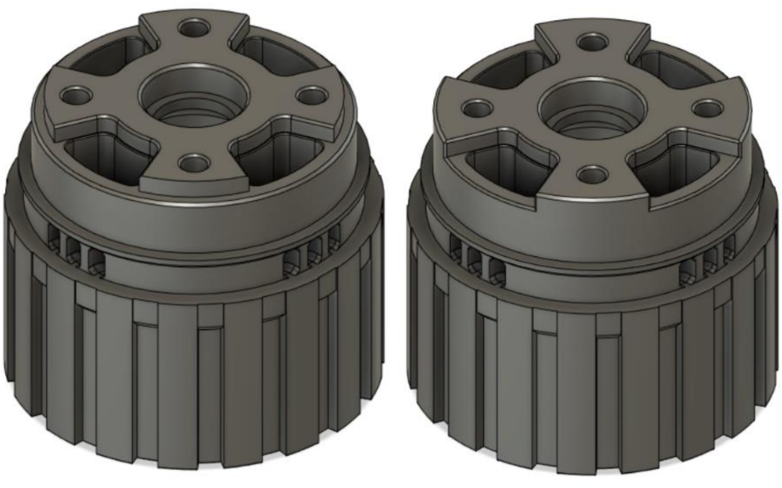

Fig.6 Concepts generated for stator

4. Materials and method of manufacture

Fused deposition modeling (FDM) is a bottom-up additive manufacturing method that involves superimposing molten material starts on a certain shape to create an object. After the first layer has been deposited, the working head rises on the working axis with the thickness of the deposited layer. The obtained objects can be independent (end-use) or be part of a certain set. Figure 7 shows a schematic representation of the operating principle of a 3D printer using this manufacturing method.

To create our parts, we use a 3D Creality Ender 3 Pro V2 printer (fig. 7) with an additional configuration with a self-calibration device BlTouch, Raspberry pi 3 and Octoprint as control software.

Fig. 7 Experimental set-up

This process has the following advantages and disadvantages.

Advantages

- Flexible design
- Reduced cost
- Fast manufacturing
- Minimal waste

Disadvantage

- Limited materials
- Need for post-processing
- Limited size

Tabel 2 Material characteristics [4]

Material characteristics	ABS	PLA
Filament diameter	1.75 mm	1.75 mm
Resistance	40 MPa	65 MPa
Stiffness	5/10	7.5/10
Durability	8/10	4/10
Printability	8/10	9/10
The maximum temperature	98°C	52°C
Coefficient of thermal expansion	90µm/m-°C	68µm/m-°C
Density	1.04g/cm^3	1.24g/cm3
Extruder temperature	235°C	190 - 220°C
Work table temperature	110°C	45 - 60°C
Work table heating	Yes	Optional
Impact resistance	Yes	-
Temperature resistance	Yes	-
Print speed	50 mm/s	70 mm/s

The materials analyzed for the parts are acrylonitrile butadiene styrene (ABS) and polylactic acid (PLA).

PLA is a thermoplastic polymer that has a fairly low transition temperature, which makes printing easier and makes it very versatile in creating different parts. This material is eco-friendly and biodegradable.

ABS has hardness and impact resistance, allowing the printing of durable parts that will have high wear resistance. ABS also has a higher transition temperature, which means that the material can withstand much higher temperatures before it starts to warp.

5. Economic analysis

A cost was made for the materials used, so an ABS (Acrylonitrile butadiene styrene) roll costs about 87 lei / piece (depending on the supplier) and has a total length of 400 m.

It has been established that 17.1 m of ABS filament are required for the manufacture of a stator and 36.4 m of filament are required for the production of the rotor. Thus, from a single roll we can make 7 rotors and 8 stators.

Also, a cost was made for a roll of PLA (Polylactic Acid) costs about 72.90 lei / piece has a total length of 400 m.

It has been established that 17.1 m of PLA filament is required to manufacture a stator, and 36.4 m of filament are required to make the rotor. Thus, from a roll, 7 rotors and 8 stators can be made.

Tabel 3. Cost

ABS (Acrilonitril butadiena stiren) – 400 m	**PLA (Acid polilactic)**
Stator: 17,1	Stator: 17,1
Rotor: 36,4	Rotor: 36,4
Can be made: 7 rotors and 8 stators	Can be made: 7 rotors and 8 stators
Total length: 400 m	Total length: 400 m
Length used: 391.6 m	Length used: 391.6 m
Calculation method: 7 x 36.4 = 254.8 (rotor) 8 x 17.1 = 136.8 (stator)	Calculation method: 7 x 36.4 = 254.8 (rotor) 8 x 17.1 = 136.8 (stator)
Cost / roll: 87 RON	Cost / roll: 72.90 RON
Material cost: 0.21 / m	Material cost: 0.18 / m
Energy cost: 44.0928 KWh * 0.8 lei / KWh = 35.27 lei	Energy cost: 44.0928 KWh * 0.8 lei / KWh = 35.27 lei
Labor: 21, 30 lei / h	Labor: 21, 30 lei / h
Equipment: 3D printer - 1600 lei	Equipment: 3D printer - 1600 lei
Maintenance: 0.03 lei / h	Maintenance: 0.03 lei / h
Total ABS cost: 1743.81 RON	Total cost of PLA: 1729.68 RON

6. Results and conclusions

After the realization of the concepts and the design of the parts, a part of the simulation of the production time followed, the amount of material necessary for the parts in the construction of the electric motor.

Table 4 shows the results of the simulations together with the output data of the parts that can be achieved through the additive manufacturing process. These results were obtained by importing meshes into Ultimaker Cure 5 slice-ing software, which generated the G code to be sent to the 3D printer.

Figure 8 shows the parts to be made by the additive method.

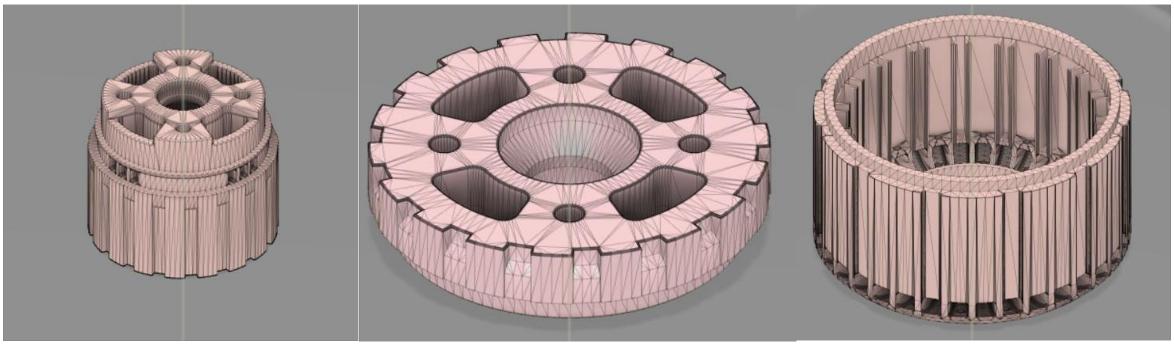

Fig. 8 Stator A (left), Stator B (middle), Rotor housing (right)

As the first production time, the calibration time was calculated, in which a measurement of the table height is performed, in 9 points, in order to make a visualization of the printing bed, fig 9. These data will be taken into account and will be adjusted. print heights so that there are no differences in height. This time will be considered as 1 minute but the calibration will be done at the table temperature of 110 ° C which will add 6 minutes to the initial time, so before each benchmark will add 7 minutes.

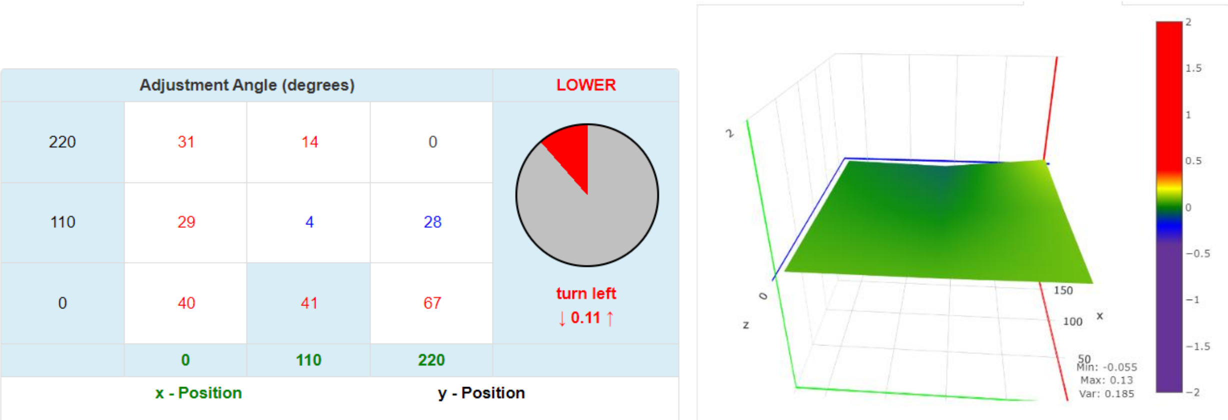

Fig. 9 Print bed calibration

Table 4 Output data

Part	Height Increase (mm)	Model fill (%)	Filing time (z: h: m)	Filament used (m)	Number of slices	Mass (g)	Support	Adhesion
Rotor - Housing V1	0,12	80	1:22:23	53,12	497	129	No	Raft
Rotor housing cover	0,16	60	10:44	20,93	104	51	No	Raft
Stator A1 amount	0,16	80	16:43	30,90	271	75	No	Raft
Stator B1 amount	0,16	80	5:39	10,61	78	26	No	Raft

According to the simulation, all the landmarks that can be printed in 3D would be made in about 3 days 7 hours 29 minutes. These data show approximately 79.48 hours. The cleaning time of the printer after each print is 2 minutes per mark.

Thus the total production time can be calculated with equation (1):

$$Tp = Tp1 + Tp2 + Tp3 + Tp4 + Tcp * 4 + Tcl * 4 \qquad (1)$$
$$Tp = 79{,}48 + 7 * 5 + 2 * 4 = 122{,}48\ h$$

where: Tp is the production time, Tp1 ... Tp4 are the individual production times, Tcp is the printer cleaning time, Tcl is the calibration time.
The actual production time is given by the relation:

$$Tpr = Tp * Te \qquad (2)$$
$$Tpr = 173{,}4 * 1.2 = 146{,}976\ h$$

where: Tpr is the actual production time and Te is a risk / failure factor that may affect the production time

The amount of material used for these parts is 115.56 m of filament (281 g).

In conclusion, following the optimization and generative design, the desired landmarks were obtained through the 3D FDM printing process, resulting in a first prototype that is the basis for product development and quality improvement.

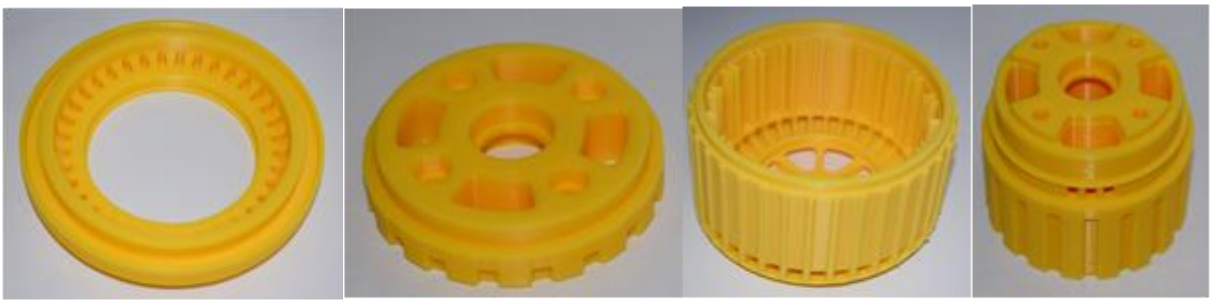

Fig. 10 Parts made
(Rotor housing cover, Stator B1 post, Housing rotor, Stator B1 post)

7. References

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